

## 25<sup>th</sup> DOE/NRC NUCLEAR AIR CLEANING AND TREATMENT CONFERENCE

### INVESTIGATION OF SHOCK/ACCELERATION REQUIREMENTS FOR CARBON FILTERS

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#### Abstract

In furtherance of the Army's effort to state system requirements in terms of performance, this investigation began the process of establishing shaking requirements for carbon filters. By obtaining acceleration data during production, transportation, and use, the Army intends to establish a reasonable shock intensity-duration envelope. Such an envelope would ensure quality performance at minimum cost.

Investigators measured accelerations in both the horizontal and vertical directions for filter cells containing two types of carbon, viz., 8 to 16 mesh coconut-based activated carbon and 12 to 30 mesh ASZM-TEDA impregnated bituminous coal-based carbon. Tests were performed while using normal production equipment and typical production procedures at a recognized manufacturer's plant. Acceleration data were gathered to assess intensity in both the horizontal and vertical directions at four fill levels for both types of carbon. Two data-gathering methods were used: (1) a computer-based accelerometer, and (2) shock overload indicating devices. As an indication of the importance of the filling-shaking process, investigators observed that, following the 100 percent-full shaking and before being "topped off," the carbon settled about 1 to 2 inches.

Tests provided three major results. First, the filter cells consistently experienced 50 or more Gs of acceleration in both the horizontal and vertical directions during the filling-shaking process at all fill levels. Second, the type of carbon did not significantly affect acceleration values. Third, there was good agreement between data obtained by the accelerometer and by the shock overload indicating devices.

Inexpensive shock overload indicating devices proved to be quite useful. Investigators recommend that, over time, acceleration data be gathered at other manufacturing plants and during shipping, transportation, and use.

#### I. Introduction

During the Army's development of a mobile igloo filter system in 1996, engineers conducted a transportation analysis to quantify environmental loads during road transport. They determined that the filter system could experience shock and vibration accelerations of 3 times gravity (G) in both the vertical and horizontal directions during transportation. Correspondingly, an interim 3 G fragility limit (defined as the minimum required acceleration to withstand expected shocks) was placed in the Army's procurement specification for the newly introduced mobile igloo filter system. Further, the Army recognized that no fragility limits had ever been established for other filter systems in its inventory. Accordingly, through a contract with Science Applications International Corporation (SAIC), the Army initiated tests to determine whether the interim 3 G fragility limit is a reasonable manufacturing standard for carbon filter cells used in its new mobile system and in many of its other systems.

SAIC planned and executed tests to measure the accelerations a typical carbon filter is likely to experience during the carbon filling process. Investigators measured accelerations in both the horizontal and vertical directions using two types of carbon, 8 to 16 mesh coconut-based activated carbon, and 12 to 30 mesh ASZM TEDA (hereafter called TEDA) carbon. SAIC performed the tests at a manufacturer's

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facility using production equipment and typical production procedures. Test runs were made for various accelerometer positions and carbon fill levels using both types of carbon. Additional runs were made to compare accelerometer measurements with shock overload indicator values.

### II. Background

Stockpiles of unitary chemical munitions are stored at various chemical munitions storage sites. These munitions are stored in protective structures called igloos where the inside air is continuously monitored by chemical analysis in an onsite chemical laboratory. When agent monitoring dictates that a munition has begun to show trace leakage, a mobile Nuclear, Biological, and Chemical (NBC) filter system is moved to the igloo, attached to the igloo's air ventilation exhaust, and then operated to reduce the agent concentration level. After a prescribed safe level has been reached, workers in protective clothing enter the igloo to locate, isolate, and containerize the leaking munition. These filter systems (both mobile and laboratory) utilize a prefilter, high efficiency particulate air (HEPA) filter, and two (in series) carbon adsorbers. The carbon adsorbers can utilize either activated or TEDA carbon, depending on the need at hand. All systems must be capable of withstanding transportation shocks and normal vibration.

To ensure adequate compacting, shock intensity imposed during manufacturing must be greater than expected during shipping, handling, and use. Commercial and government standards often require that an adsorber be dropped 3/4 inch to a steel surface at a cyclic frequency of 200 cycles per minute (cpm). The duration (time) and shock level (Gs) are generally not specified. The absence of a completely defined manufacturing shock standard gave rise to this study.

### III. Test Approach

Test Location. The testing was performed at the Flanders/CSC facilities in Bath, North Carolina. The tests were conducted in the building that is normally used to fill the production filter cells with carbon.

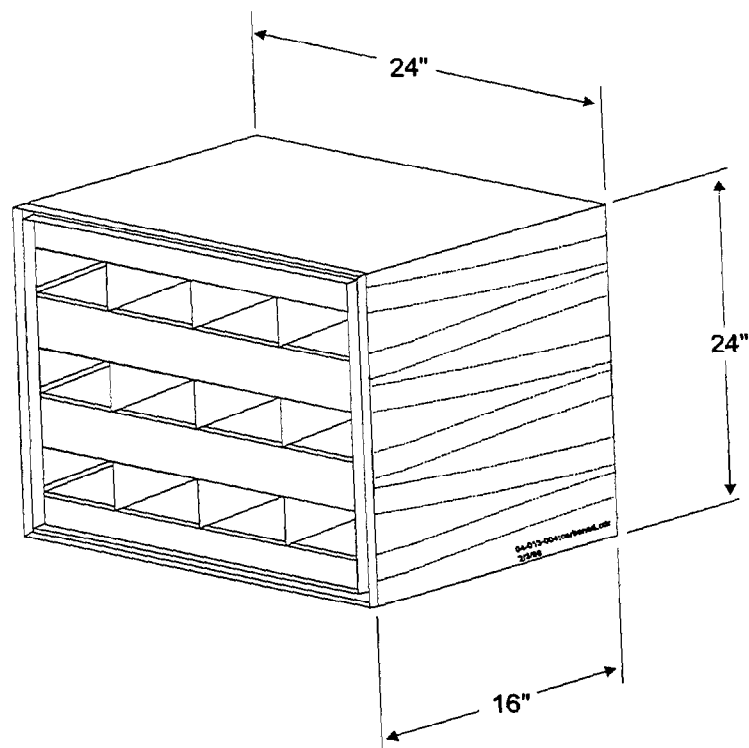
Test Schedule. The testing took place on December 2 and 3, 1997. Phases 1 and 2 of the tests were performed by SAIC on December 2. Phases 3 and 4 were performed on December 3 with government representatives present.

Equipment. For this test, normal production equipment and typical production methods were used. Investigators elected to fill and shake the adsorbers in five increments (about 25 percent, 50 percent, 75 percent, 100 percent, and after topping off, again 100 percent). A rough handling machine (RHM), or bump tester, was used to pack the carbon into the adsorber cell. This machine uses cams to lift and drop a table onto a solid base. Its table is cyclically raised and dropped 3/4 inch at a frequency of 200 cpm. The filter cell rests on top of the table during the filling process. The cell is not strapped to the RHM but is restrained by hand to keep it from bouncing off. This practice gives infinite degrees of freedom to the cell during shaking. Approximately 3 cubic feet of carbon was used for each test. A typical adsorber cell is shown in figure 1.

Instrumentation. Two types of instruments were used for the tests. The first type provided a visual indication when a certain shock acceleration value was exceeded. The second type provides measured acceleration value over time. These instruments are described below.

The selected shock overload indicator is a reusable spring-loaded device (a "go/no-go" device) that shows a red bar when the induced acceleration exceeds the device's design rating. To cover the estimated range of accelerations, shock devices rated for 3 G, 10 G, and 40 G were used for this test. Figure 2 shows three of these devices mounted on the RHM.

In order to measure and display the shock values over time, a personal computer-based data acquisition system coupled to an accelerometer was used. This system permitted the test data to be viewed in real time and recorded for later analysis. The system components consisted of an accelerometer with a 0 to 50 G linear range, a +/- 5 volts direct current (VDC) signal conditioner, an analog/digital interface box, a computer data acquisition controller card, and a Pentium computer.



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Test Procedure. The testing was divided into five distinct steps. The initial step involved the equipment setup and instrumentation end-to-end verification. Phase 1 tests provided data on the RHM and the empty filter cell. Phase 2 tests provided data during the fill process using the nuclear-grade carbon. Phase 3 tests were a repeat of the Phase 1 tests (for validation). Phase 4 tests were similar to the Phase 2 tests except that TEDA carbon was used.

Equipment Setup and Verification. The equipment used for the computer data acquisition system was unpacked and the cables were connected. The computer was started up and sample test results were viewed to ensure that the system was operating properly. The accelerometer was held with its face upward, and then it was then rotated downward and upward several times. This was done to verify that the equipment properly measured accelerations that varied from +1 G to -1 G. After the equipment was found to be operating properly and in calibration, the next phases of the test were started.

Phase 1 Tests. Phase 1 tests were performed to obtain reference data on the RHM alone and on the RHM and empty filter cell. This data would indicate if any acceleration reduction occurs during the filling process. The test runs and procedures utilized were as follows:

Run 1. Three shock overload indicating devices were attached to the center portion of the RHM table (filter absent) using duct tape to assess vertical acceleration. The RHM was turned on for approximately 10 seconds and then shut off. The condition of the devices (set or tripped) was observed.

Run 2. Run 1 was repeated except that an accelerometer was also attached to the RHM using double-sided tape to measure vertical acceleration. Accelerometer readings were recorded and the condition of the shock overload devices (set or tripped) was observed.

Run 3. An empty filter cell was placed onto the RHM table and the accelerometer was mounted to the cell's top surface rather than to the RHM. The RHM was turned on for approximately 10 seconds and accelerometer readings were recorded.

Phase 2 Tests. During Phase 2 tests, the filter cells were incrementally filled with activated carbon, shaken on the RHM, and acceleration measurements taken for varying carbon fill levels. In some runs, accelerations were measured in a vertical plane; in other runs in a horizontal plane (either from the front or the side); and in still other runs in a plane normal to the carbon bed. Figure 3 shows a typical test setup. Runs 4 through 15 comprised Phase 2. For Runs 4 through 8, the test setup and procedures were the same as those for Run 3 except that the adsorber cell was:

In Run 4, filled to about 25 percent full,

In Run 5, filled to about 50 percent full,

In Run 6, filled to about 75 percent full, and

In Run 7, filled to about 100 percent full. The fill level diminished by 1 to 2 inches during Run 7 owing to compaction.

In Run 8, the adsorber, was refilled (topped off) and Run 7 procedures were repeated. All measurements and shock indicator observations through Run 8 reflected vertical accelerations.

In Run 9 and Run 10, the setup and test procedures followed in Run 8 were repeated except that the accelerometer was repositioned to the side (Run 9) and the front (Run 10) to measure horizontal accelerations.

In Run 11, an empty cell was placed onto the RHM table and the accelerometer was mounted on the screen normal to the filter bed with double-sided tape. Figure 4 shows the test setup. The RHM was turned on for approximately 10 seconds and accelerometer measurements were recorded.

In Runs 12 through 16, the same setup and procedures as used in Run 11 were applied except that the adsorber cell was filled:

In Run 12, to about 25 percent full,

In Run 13, to about 50 percent full,

In Run 14, to about 75 percent full, and

In Run 15, to about 100 percent full.

In Run 16 the adsorber was refilled (topped off) and Run 15 was repeated.

Phase 3 Tests. The Phase 3 tests (for validation) were a repeat of the Phase 1 tests and involved the RHM and the empty filter cell. The tests runs and procedures utilized were as follows:

In Run 17, the three shock overload indicating devices were attached to the center portion of the RHM table using duct tape. The RHM was turned on for approximately 10 seconds and the condition of the devices (set or tripped) was observed.

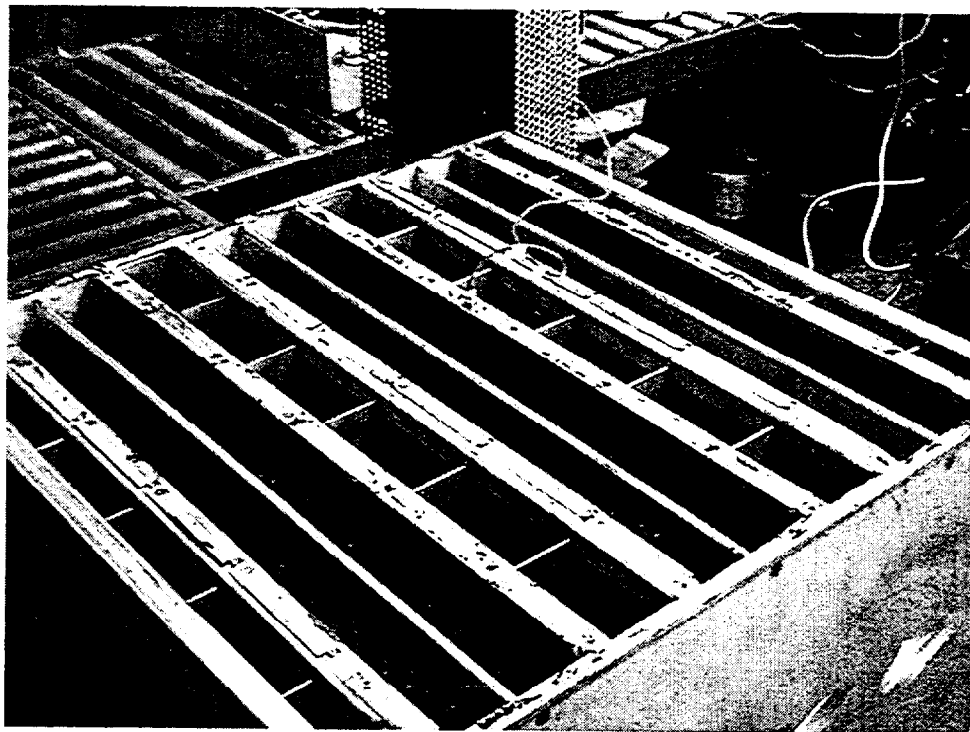


Figure 3. Accelerometer Location on Filter Cell (Vertical)

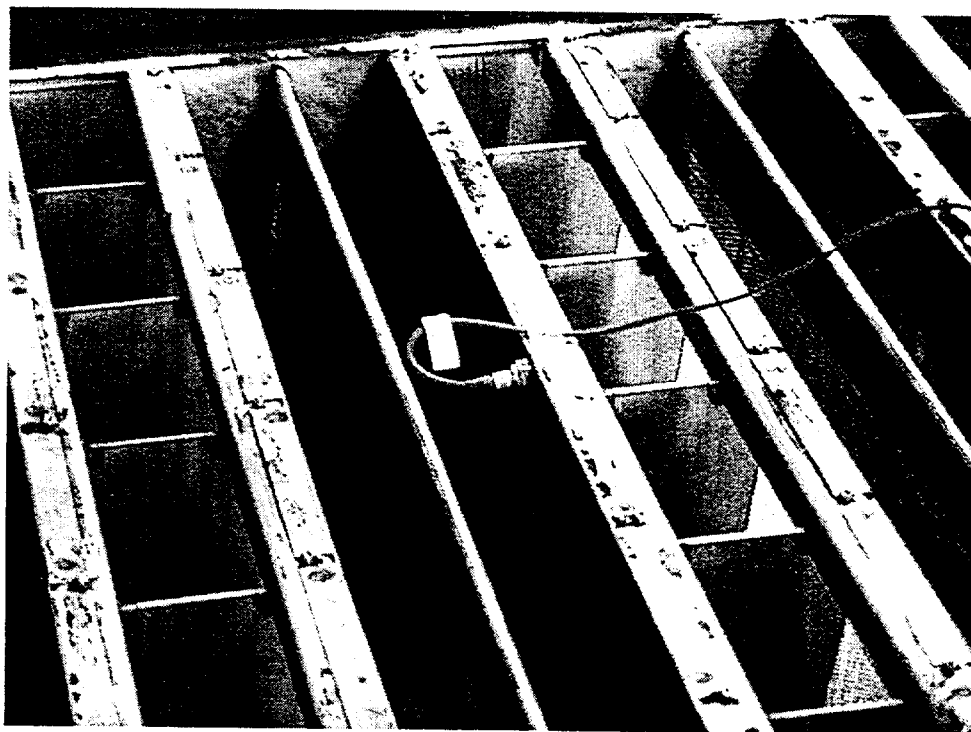


Figure 4. Accelerometer Location on Filter Cell (Normal to Bed)

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In Run 18, the same setup was used as in Run 17 except that the accelerometer was then attached to the RHM using double-sided tape. The RHM was turned on for approximately 10 seconds. Accelerometer readings were recorded and the condition of the devices (set or tripped) was observed.

In Run 19, an empty filter cell was placed onto the RHM table and the accelerometer was mounted to the top surface with double-sided tape to measure vertical accelerations. The RHM was turned on for approximately 10 seconds. Accelerometer readings were recorded.

**Phase 4 Tests.** The Phase 4 tests were the same as the Phase 2 tests except that the filter cell was filled with TEDA carbon. This test was performed to determine whether the accelerations were affected by the type of carbon used during the filling process. The test setup and testing procedures utilized in Run 19 were followed except that the adsorber cell was filled:

In Run 20, to about 25 percent full,

In Run 21, to about 50 percent full,

In Run 22, to about 75 percent full, and

In Run 23, to about 100 percent full.

In Run 24, the cell was refilled (topped off) and the procedure of Run 23 was repeated.

In Run 25, the accelerometer was mounted normal to the screen and the procedure of Run 24 was repeated.

### IV. Test Results

**Instrument End-to-End Verification.** To ensure that the instruments and data acquisition system were set up and working properly, the accelerometer was verified using the earth's gravity. The accelerometer was held with its face upward, and then rotated downward and upward several times. The response was expected to vary from +1 G to -1 G. The results are shown in figure 5. The fact that the measured response oscillated between +1 G and -1 G showed that the equipment was working properly.

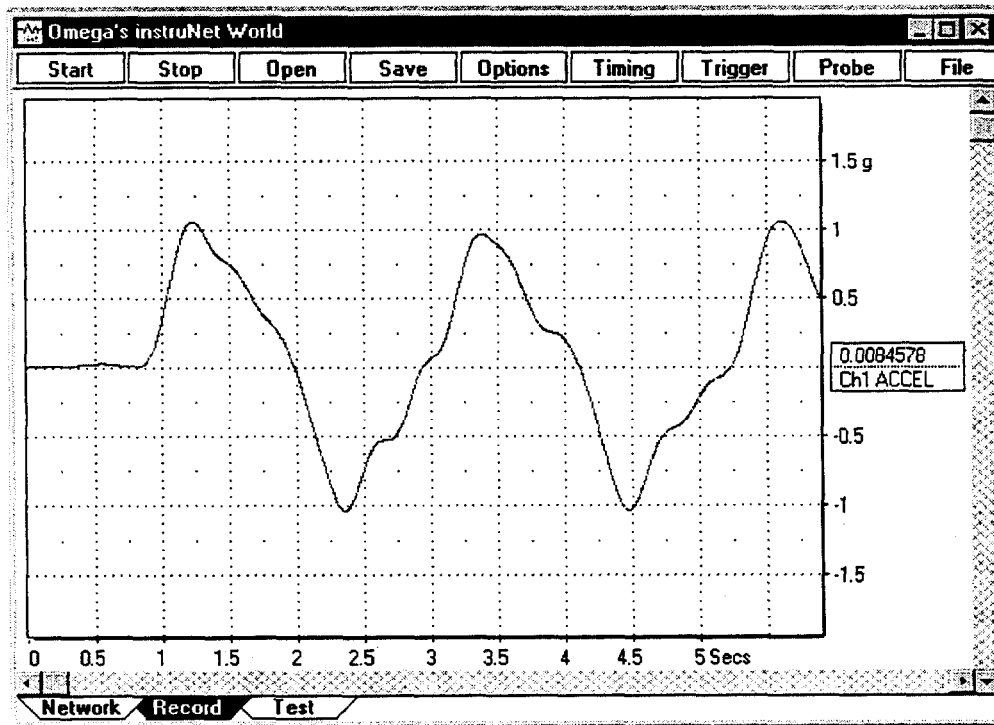


Figure 5. Instrument End-to-End Verification

**Phase 1 Results.** Runs 1 and 2 were performed using the shock overload indicating devices attached directly to the RHM table. In each of the two runs, the 3 G, 10 G, and 40 G shock devices all tripped within 5 seconds and provided a red bar visual indication that the rated shock values for the devices had been exceeded. In Run 2, the accelerometer was also used. Figure 6 shows the accelerometer results from Run 2. The shock values all exceeded 50 Gs which verified the performance of the shock overload indicating devices. Table 1 provides a summary of the Phase 1 test results. [Note: the nominal maximum recordable acceleration is 50 Gs. Notice the peaks are flattened (chopped off) at values just under 50 Gs.]

Figure 6 shows the first four acceleration bursts resulting from the table impacting on the anvil. Each burst consists of a short duration (approximately 10 milliseconds) of forced response followed by an extended period of structural ringing, as shown in the detail of figure 7. The curves vary because each impact is slightly different: some impacts hit first on one corner, some hit squarely on all four corners, etc. In all cases, the impact excites structural ringing of the table. Each peak (of roughly 1 millisecond duration) corresponds to the distinct impact of one corner of the table.

The detail in figure 7 shows a typical response in which the filter cell impacts separately on all four corners. The first corner impacts at 0.2852 seconds, the second at 0.286 seconds, and the third at roughly 0.287 seconds. The subsequent response is due to rebound, multiple impact, and structural resonance of the table.

In Run 3, the accelerometer was mounted to the top surface of an empty cell that was positioned on top of the RHM. (See figure 8.) Accelerometer readings all exceeded 50 Gs. These results indicated that there was no noticeable loss of shock-induced acceleration between the RHM and the filter cell.

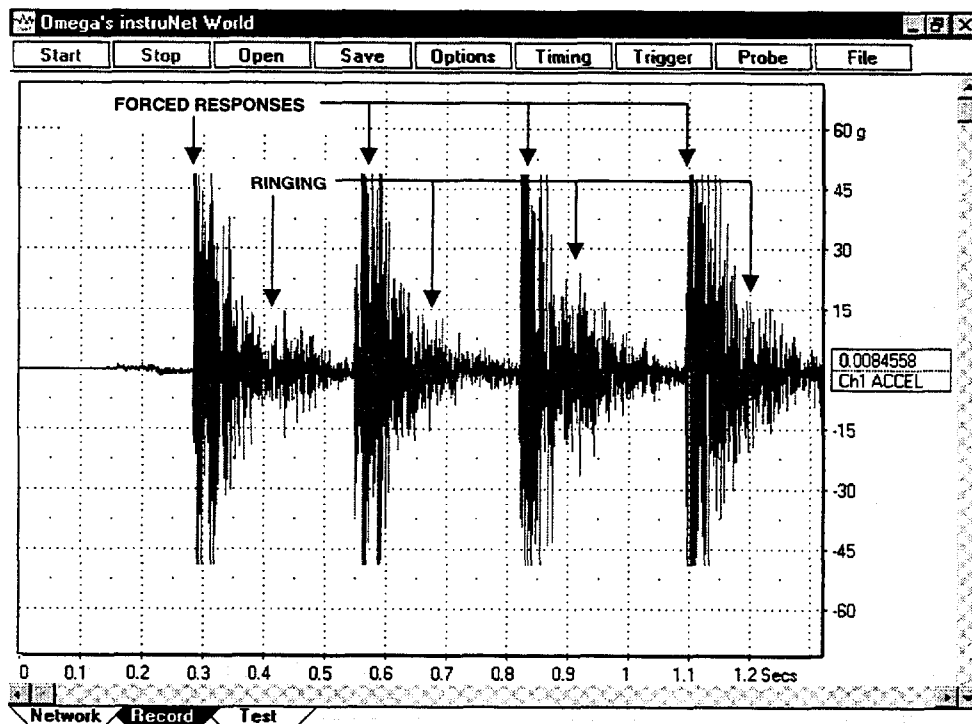


Figure 6. Run 2 – Vertical Acceleration of the Table Only

Table 1. Phase 1 Test Results

Test Run	Test Setup	Shock Device Status	Acceleration - Gs
1	RHM Table	3 G, 10 G, 40 G Tripped	Not Measured
2	RHM Table	3 G, 10 G, 40 G Tripped	50
3	Empty Cell	Not Used	50

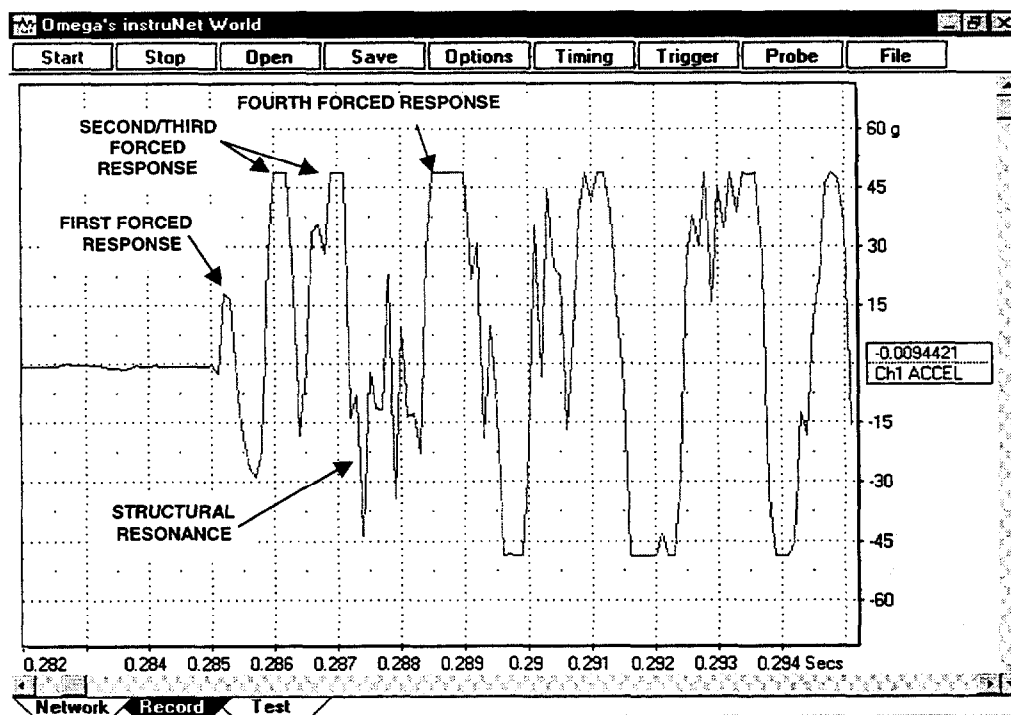


Figure 7. Run 2 – Detail of Table-Only Impact



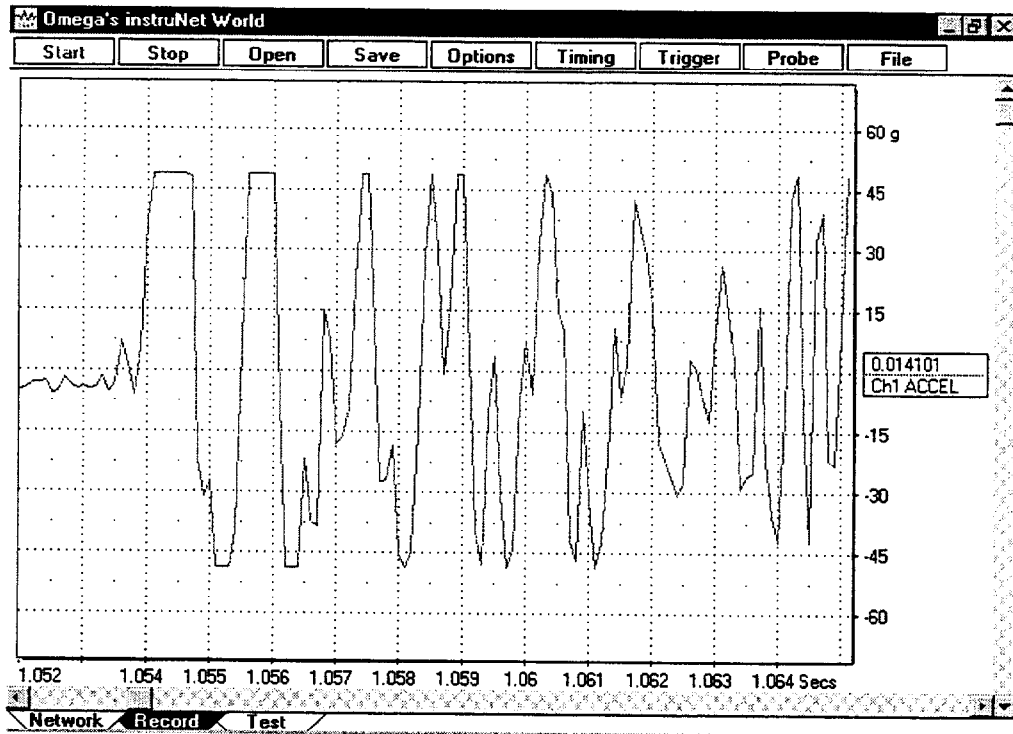


Figure 8. Run 3 – Vertical Acceleration of an Empty Filter Cell

**Phase 2 Results.** In Runs 4 through 8, the accelerometer was mounted on the top of the filter cell. The filter cell was filled with activated carbon. The fill levels ranged from 25, 50, 75, and 100 percent full, and topped off. Settling of 1 to 2 inches occurred when the cell was shaken at the 100 percent level before being topped off. The greatest amount of settling occurred near the side walls. During each of these fills, the accelerometer readings indicated that the vertical accelerations were consistently at or in excess of 50 Gs. Figure 9 shows the results from Run 8. The significant effect of the carbon fill is the mechanical damping which results in considerably less structural resonance being exhibited.

In Runs 9 and 10, the accelerometer was attached to the side and front of the filter cell when the filter cell was 100 percent full and topped off. During each of these runs the accelerometer readings were in excess of 50 Gs. (See figure 10.) This indicated that the horizontal accelerations, as measured in two locations, were consistent with the vertical accelerations.

In Runs 11 through 16, the accelerometer was attached to the inside surface of the filter screen. After testing an empty cell, the cell was incrementally filled with activated carbon. The fills ranged from 25, 50, 75, and 100 percent full, then topped off. (See table 2.) At each of these fill levels, the accelerometer readings were in excess of 50 Gs. This indicated that the accelerations normal to the filter bed were also consistent with the vertical accelerations. See figure 11 for the test results. Table 2 provides a summary of the Phase 2 test results.

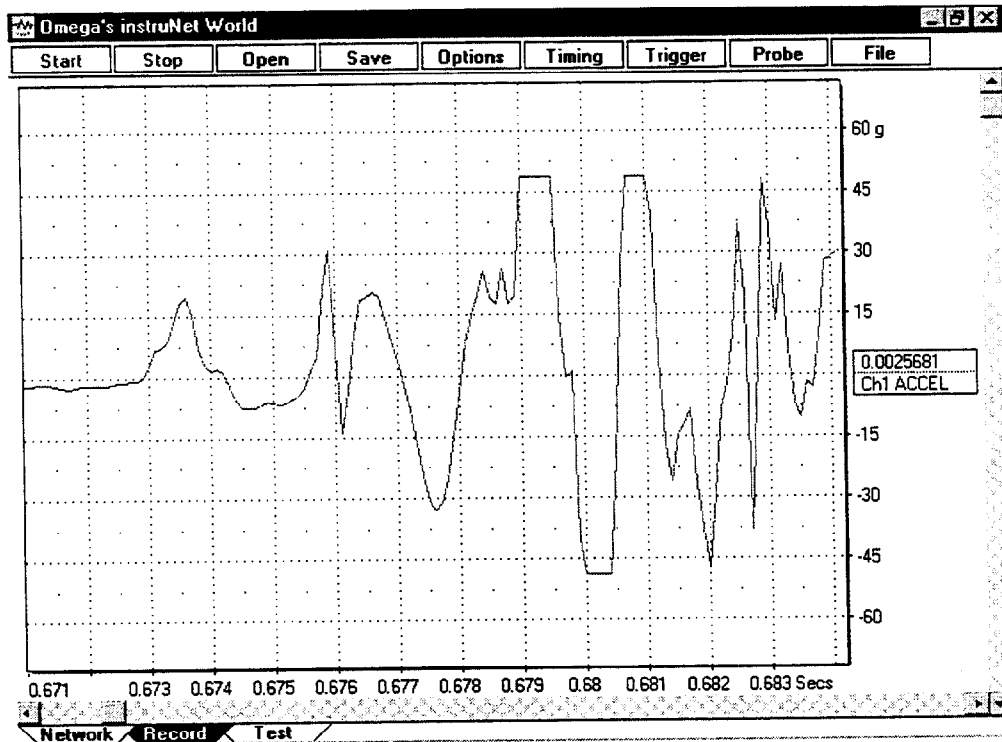


Figure 9. Run 8 – Vertical Acceleration of a 100 Percent-Filled Cell

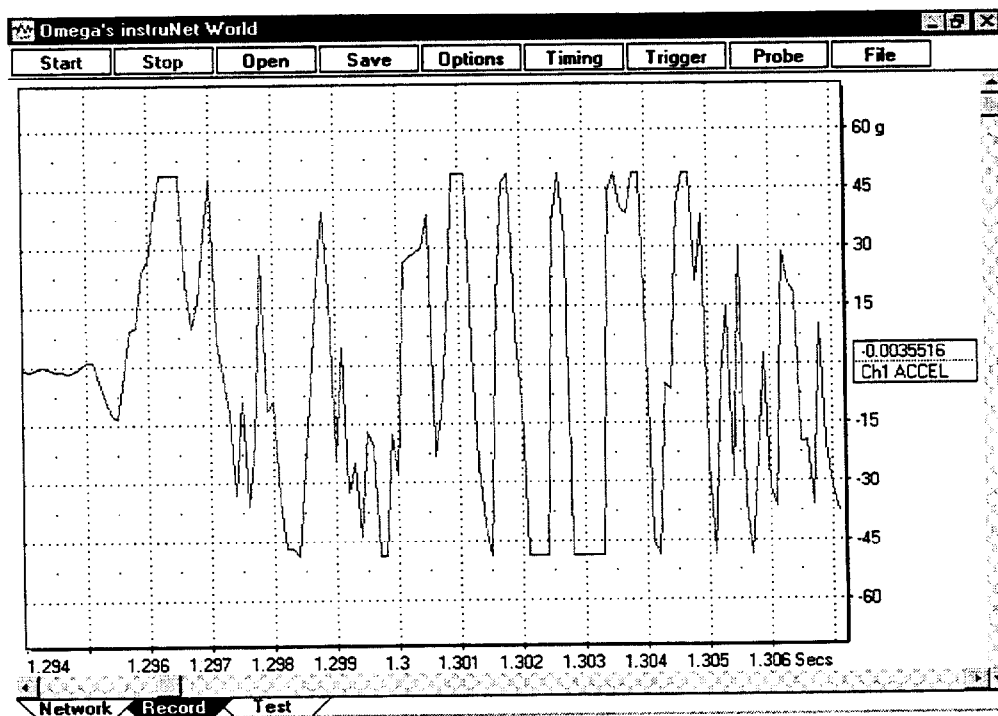


Figure 10. Run 9 - Lateral Acceleration of a 100 Percent-Filled Cell

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Table 2. Phase 2 Test Results

Test Run	Accelerometer Axis	Percent Full	Acceleration - Gs
4	Cell Top	25	50
5	Cell Top	50	50
6	Cell Top	75	50
7	Cell Top	100	50
8	Cell Top	100 Topped Off	50
9	Cell Side	100 Topped Off	50
10	Cell Front	100 Topped Off	50
11	Normal to Bed	Cell Empty	50
12	Normal to Bed	25	50
13	Normal to Bed	50	50
14	Normal to Bed	75	50
15	Normal to Bed	100	50
16	Normal to Bed	100 Topped Off	50

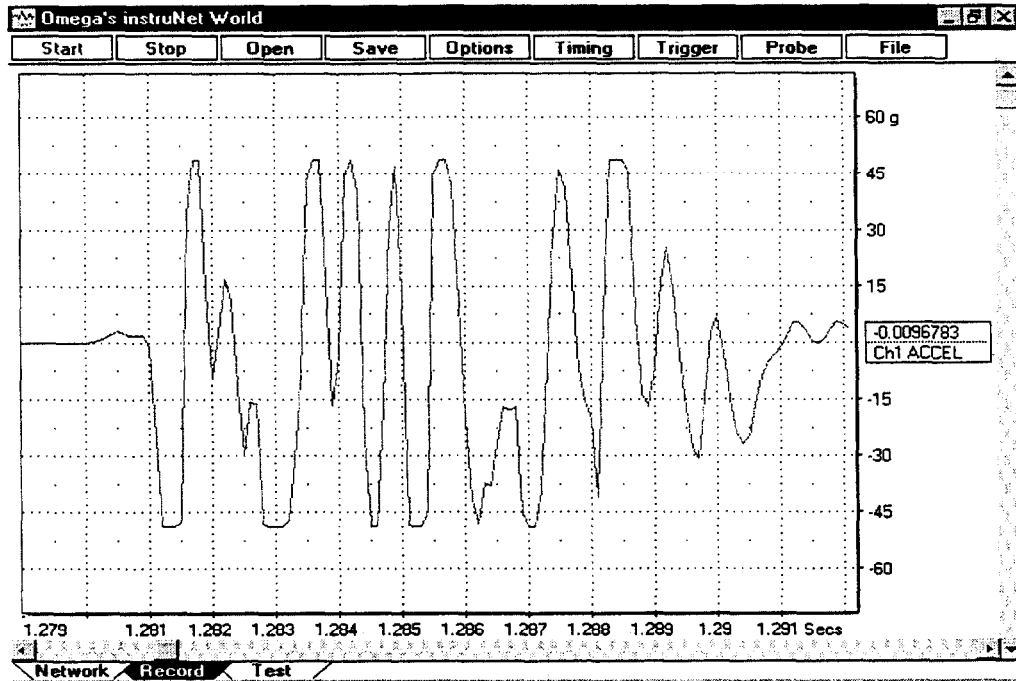


Figure 11. Run 15 – Bed Normal Acceleration of a 100 Percent-Filled Cell

**Phase 3 Results.** The Phase 3 tests were performed to demonstrate both the RHM and RHM and empty cell combination characteristics to the Army representatives. Table 3 provides a summary of the Phase 3 test results. Runs 17 and 18 were performed using the shock overload indicating devices attached directly to the RHM table. In each of the two runs, the 3 G, 10 G, and 40 G shock devices all tripped within 5 seconds and provided a red bar visual indication that the rated shock values for the devices had been exceeded. In Run 18, the accelerometer was also mounted to the table. The shock values all exceeded 50 Gs which verified the performance of the shock overload indicating devices. In Run 19, the accelerometer was mounted to the top surface of an empty cell that was positioned on top of the RHM. The accelerometer readings all exceeded 50 Gs. These results indicated that there was no noticeable loss of shock-induced acceleration between the RHM and the filter cell. The acceleration results were similar to those shown in figures 7, 8, and 9.

**Phase 4 Results.** In Runs 20 through 25, the accelerometer was mounted on the top of the filter cell. The filter cell was incrementally filled with TEDA carbon. The fill levels ranged from 25, 50, 75, and 100 percent full, then topped off. Settling of 1 to 2 inches occurred when the cell was shaken at the 100 percent level, before being topped off. The greatest amount of settling occurred near the side wall. During each of these fills, the accelerometer readings were consistently at or in excess of 50 Gs. See figure 12 for the test results.

In Run 25, the accelerometer was attached to the inside surface of the filter screen. The filter cell was refilled 100 percent and topped off with TEDA carbon and shaken for 10 seconds. The accelerometer readings were at or in excess of 50 Gs. This indicated that accelerations normal to the filter bed were also consistent with vertical accelerations. (See figure 13.) Table 4 provides a summary of the Phase 4 test results.

Table 3. Phase 3 Test Results

Test Run	Test Setup	Shock Device Status	Acceleration - Gs
17	RHM Table	3 G, 10 G, 40 G Tripped	Not Measured
18	RHM Table	3 G, 10 G, 40 G Tripped	50
19	Empty Cell	Not Used	50

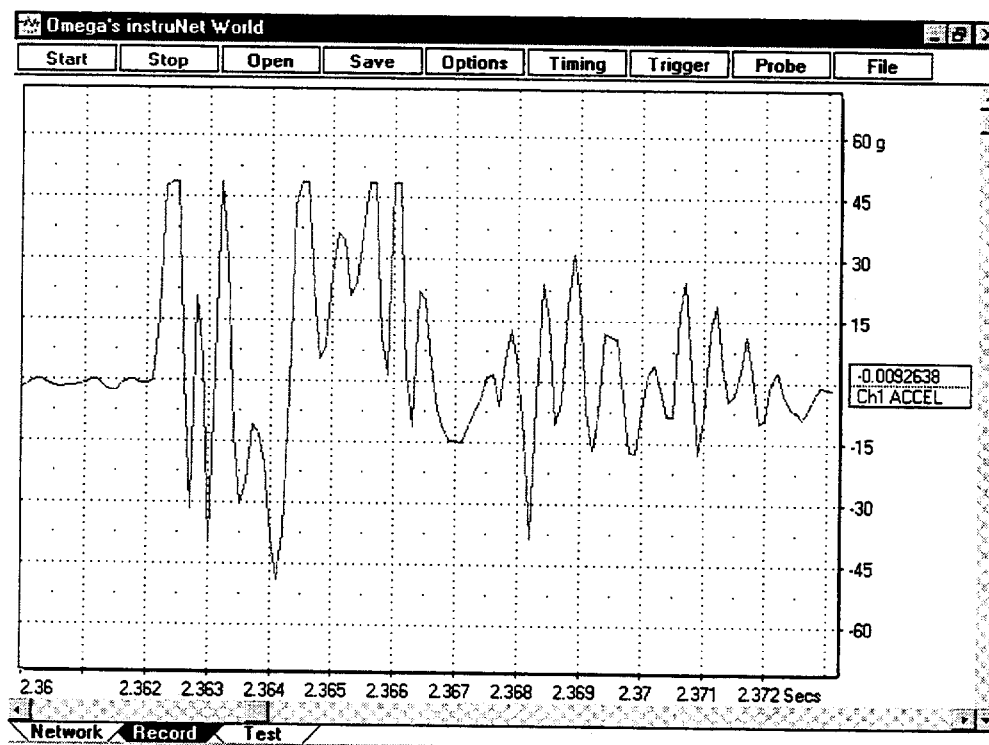


Figure 12. Run 24 - Vertical Acceleration of a 100 Percent-Filled TEDA Cell

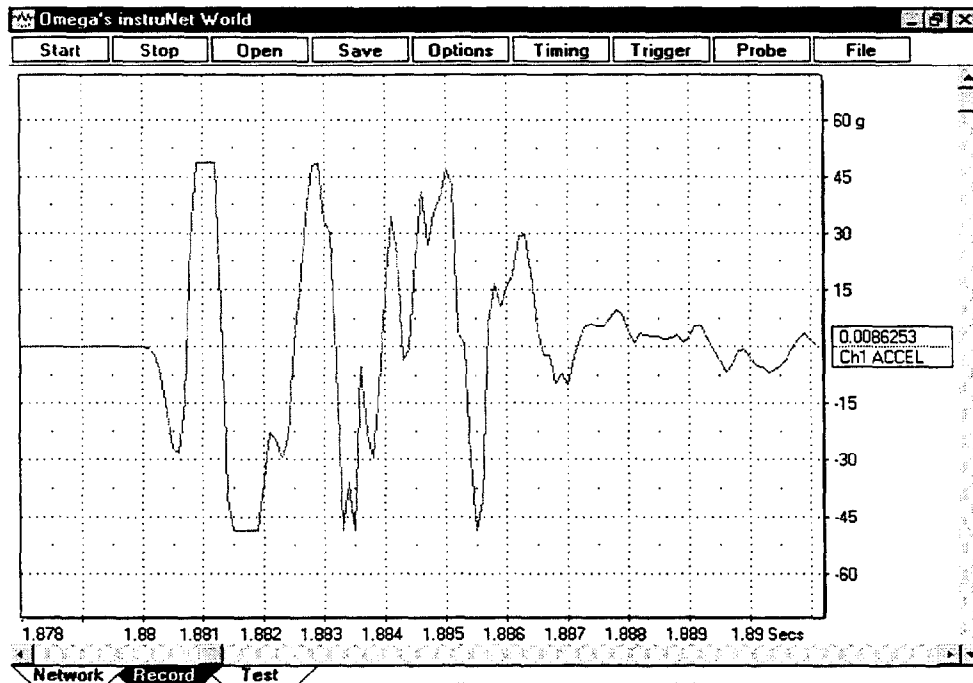


Figure 13. Run 25 – Bed Normal Acceleration of a 100 Percent-Filled TEDA Cell

Table 4. Phase 4 Test Results

Test Run	Accelerometer Axis	Percent Full	Acceleration - Gs
20	Cell Top	25	50
21	Cell Top	50	50
22	Cell Top	75	50
23	Cell Top	100	50
24	Cell Top	100 Topped Off	50
25	Normal to Bed	100 Topped Off	50

V. Conclusions

This testing demonstrated that during normal production carbon fill procedures, the filter cells consistently experience acceleration at or in excess of 50 Gs in both the vertical and horizontal directions.

The maximum acceleration measured on the filter cell was independent of the accelerometer location, percent of cell filled, and type of carbon used.

For both the activated and TEDA carbon, there is a considerable amount of settling that occurs during the filling process, with the greatest settling occurring near the side walls of the filter cell.

Shock overload indicating devices provide a simple and accurate visual method of verifying whether equipment has experienced shock loads that exceed certain rated limits.

This testing revealed that the interim 3 G fragility limit identified in the mobile igloo filter system procurement specification was quite low and given the observed settling, should be increased for the carbon filter cell.

Additional testing should be performed to determine shock levels that a filter cell can experience during shipping, transportation, and use, for example, post-manufacturing shock.

Shock overload indicating devices could provide an inexpensive means for shock determinations in the future.